# CHAPTER 3

# BOILER EMISSIONS

## 3-1. Generation processes

The combustion of a fuel for the generation of steam or hot water results in the emission of various gases and particulate matter. The respective amounts and chemical composition of these emissions formed are dependent upon variables occurring within the combustion process. The interrelationships of these variables do not permit direct interpretation by current analytical methods. Therefore, most emission estimates are based upon factors compiled through extensive field testing and are related to the fuel type, the boiler type and size, and the method of firing. Although the use of emission factors based on the above parameters can yield an accurate first approximation of on-site boiler emissions, these factors do not reflect individual boiler operating practices or equipment conditions, both of which have a major influence on emission rates. A properly operated and maintained boiler requires less fuel to generate steam efficiently thereby reducing the amount of ash, nitrogen and sulfur entering the boiler and the amount of ash, hydrocarbons, nitrogen oxides ($NO_x$) and sulfur oxides ($SO_x$) exiting in the flue gas stream. Emissions from conventional boilers are discussed in this chapter. Chapter 13 deals with emissions from fluidized bed boilers.

## 3-2. Types of fuels

*a. Coal.* Coal is potentially a high emission producing fuel because it is a solid and can contain large percentages of sulfur, nitrogen, and noncombustibles. Coal is generally classified, or “ranked”, according to heating value, carbon content, and volatile matter. Coal ranking is important to the boiler operator because it describes the burning characteristics of a particular coal type and its equipment requirements. The main coal fuel types are bituminous, subbituminous, anthracite, and lignite. Bituminous is most common. Classifications and analyses of coal may be found in "Perry's Chemical Engineering Handbook".

*b. Fuel oil.* Analyses of fuel oil may be found in "Perry's Chemical Engineering Handbook".

(1) *Distillates.* The lighter grades of fuel oil (No.1, No.2) are called distillates. Distillates are clean burning relative to the heavier grades because they contain smaller amounts of sediment, sulfur, ash, and nitrogen and can be fired in a variety of burner types without a need for preheating.

(2) *Residuals.* Residual fuel oils (No.4, No.5, No.6) contain a greater amount of ash, sediment, sulfur, and nitrogen than is contained in distillates. They are not as clean burning as the distillate grades.

*c. Gaseous fuel.* Natural gas, and to a limited extent liquid petroleum (butane and propane) are ideally suited for steam generation because they lend themselves to easy load control and require low amounts of excess air for complete combustion. (Excess air is defined as that quantity of air present in a combustion chamber in excess of the air required for stoichiometric combustion). Emission levels for gas firing are low because gas contains little or no solid residues, noncombustibles, and sulfur. Analyses of gaseous fuels may be found in "Perry's Chemical Engineering Handbook”.

*d. Bark and wood waste.* Wood bark and wood waste, such as sawdust, chips and shavings, have long been used as a boiler fuel in the pulp and paper and wood products industries. Because of the fuel's relatively low cost and low sulfur content, their use outside these industries is becoming commonplace. Analyses of bark and wood waste may be found in Environmental Protection Agency, "Control Techniques for Particulate Emissions from Stationary Sources”. The fuel's low heating value, 4000-4500 British thermal units per pound (Btu/lb), results from its high moisture content (50-55 percent).

*e. Municipal solid waste (MSW) and refuse derived fuel (RDF).* Municipal solid waste has historically been incinerated. Only recently has it been used as a boiler fuel to recover its heat content. Refuse derived fuel is basically municipal solid waste that has been prepared to burn more effectively in a boiler. Cans and other noncombustibles are removed and the waste is reduced to a more uniform size. Environmental Protection Agency, "Control Techniques for Particulate Emissions from Stationary Sources" gives characteristics of refuse derived fuels.

## 3-3. Fuel burning systems

*a. Primary function.* A fuel burning system provides controlled and efficient combustion with a minimum emission of air pollutants. In order to achieve this goal, a fuel burning system must prepare, distribute, and mix the air and fuel reactants at the optimum concentration and temperature.

*b. Types of equipment.*

(1) *Traveling grate stokers.* Traveling grate stokers are used to burn all solid fuels except heavily caking coal types. Ash carryout from the furnace is held to a minimum through use of overfire air or use of the rear arch furnace design. At high firing rates, however; as much as 30 percent of the fuel ash content may be entrained in the exhaust gases from grate type stokers. Even with efficient operation of a grate stoker, 10 to 30 percent of the particulate emission weight generally consists of unburned combustibles.

(2) *Spreader stokers.* Spreader stokers operate on the combined principles of suspension burning and nonagitated type of grate burning. Particulate emissions from spreader stoker fired boilers are much higher than those from fuel bed burning stokers such as the traveling grate design, because much of the burning is done in suspension. The fly ash emission measured at the furnace outlet will depend upon the firing rate, fuel sizing, percent of ash contained in the fuel, and whether or not a fly ash reinjection system is employed.

(3) *Pulverized coal burners.* A pulverized coal fired installation represents one of the most modern and efficient methods for burning most coal types. Combustion is more complete because the fuel is pulverized into smaller particles which require less time to burn and the fuel is burned in suspension where a better mixing of the fuel and air can be obtained. Consequently, a very small percentage of unburned carbon remains in the boiler fly ash. Although combustion efficiency is high, suspension burning increases ash carry over from the furnace in the stack gases, creating high particulate emissions. Fly ash carry over can be minimized by the use of tangentially fired furnaces and furnaces designed to operate at temperatures high enough to melt and fuse the ash into slag which is drained from the furnace bottom. Tangentially fired furnaces and slag-tap furnaces decrease the amount of fuel ash emitted as particulates with an increase in $NO_x$ emissions.

(4) *Fuel oil burners.* Fuel oil may be prepared for combustion by use of mechanical atomizing burners or twin oil burners. In order for fuel oil to be properly atomized for combustion, it must meet the burner manufacturer's requirements for viscosity. A fuel oil not heated to the proper viscosity cannot be finely atomized and will not burn completely. Therefore, unburned carbon or oil droplets will exit in the furnace flue gases. A fuel oil heated above the proper viscosity may ignite too rapidly forming pulsations and zones of incomplete combustion at the burner tip. Most burners require an atomizing viscosity between 100 and 200 Saybolt Universal Seconds (SUS); 150 SUS is generally specified.

(5) *Municipal solid waste and refuse derived fuel burning equipment.* Large quantities of MSW are fired in water tube boilers with overfeed stokers on traveling or vibrating grates. Smaller quantities are fired in shop assembled hopper or ram fed boilers. These units consist of primary and secondary combustion chambers followed by a waste heat boiler. The combustion system is essentially the same as the "controlled-air" incinerator described in paragraph 2-5(b)(5). The type of boiler used for RDF depends on the characteristics of the fuel. Fine RDF is fired in suspension. Pelletized or shredded RDF is fired on a spreader stoker. RDF is commonly fired in combination with coal, with RDF constituting 10 to 50 percent of the heat input.

## 3-4. Emission standards

The Clean Air Act requires all states to issue regulations regarding the limits of particulate, $SO_x$ and $NO_x$ emissions from fuel burning sources. State and local regulations are subject to change and must be reviewed prior to selecting any air pollution control device. Table 31 shows current applicable Federal Regulations for coal, fuel oil, and natural gas. The above allowable emission rates shown are for boilers with a heat input of 250 million British thermal units (MMBtu) and above.

*Table 3–1*
*Allowable federal emission rates*

| Fuel | Particulate | $SO_2$ | $NO_x$ | Opacity |
|---|---|---|---|---|
| Coal | 0.1 lb/MMBtu | 1.2 lb/MMBtu | .7 lb/MMBtu | 20 Percent |
| Fuel Oil | 0.1 lb/MMBtu | 0.8 lb/MMBtu | .3 lb/MMBtu | 20 Percent |
| Natural Gas | 0.1 lb/MMBtu | — | .2 lb/MMBtu | 20 Percent |

From: 40CFR86—"National Primary and Secondary Ambient Air Quality Standards".

## 3-5. Formation of emissions

*a. Combustion parameters.* In all fossil fuel burning boilers, it is desirable to achieve a high degree of combustion efficiency, thereby reducing fuel consumption and the formation of air pollutants. For each particular type fuel there must be sufficient time, proper temperature, and adequate fuel/air mixing to insure complete combustion of the fuel. A deficiency in any of these three requirements will lead to incomplete combustion and higher levels of particulate emission in the form of unburned hydrocarbon. An excess in time, temperature, and fuel/air mixing will increase the boiler formation of gaseous emissions ($NO_x$). Therefore, there is some optimum value for these three requirements within the boiler's operating range which must be met and maintained in order to minimize emission rates. The optimum values for time, temperature, and fuel-air mixing are dependent upon the nature of the fuel (gaseous, liquid or solid) and the design of the fuel burning equipment and boiler.

*b. Fuel type.*

(1) *Gaseous fuels.* Gaseous fuels burn more readily and completely than other fuels. Because they are in molecular form, they are easily mixed with the air required for combustion, and are oxidized in less time than is required to burn other fuel types. Consequently, the amount of fuel/air mixing and the level of excess air needed to burn other fuels are minimized in gas combustion, resulting in reduced levels of emissions.

(2) *Solid and liquid fuels.* Solid and liquid fuels require more time for complete burning because they are fired in droplet or particle form. The solid particles or fuel droplets must be burned off in stages while constantly being mixed or swept by the combustion air. The size of the droplet or fired particle determines how much time is required for complete combustion, and whether the fuel must be burned on a grate or can be burned in suspension. Systems designed to fire solid or liquid fuels employ a high degree of turbulence (mixing of fuel and air) to complete combustion in ‘the required time, without a need for high levels of excess air or extremely long combustion gas paths. As a result of the limits imposed by practical boiler design and necessity of high temperature and turbulence to complete particle burnout, solid and liquid fuels develop higher emission levels than those produced in gas firing.

## 3-6. Fuel selection

Several factors must be considered when selecting a fuel to be used in a boiler facility. All fuels are not available in some areas. The cost of the fuel must be factored into any economic study. Since fuel costs vary geographically, actual delivered costs for the particular area should be used. The capital and operating costs of boiler and emission control equipment vary greatly depending on the type of fuel to be used. The method and cost of ash disposal depend upon the fuel and the site to be used. Federal, state and local regulations may also have a bearing on fuel selection. The Power Plant and Fuel Use Act of 1978 requires that a new boiler installation with heat input greater than 100 MMBtu have the capability to use a fuel other than oil or natural gas. The Act also limits the amount of oil and natural gas firing in existing facilities. There are also regulations within various branches of the military service regarding fuel selection, such as AR 420-49 for the Army's use.

## 3-7. Emission factors

Emission factors for particulates, $SO_x$ and $NO_x$, are presented in the following paragraphs. Emission factors were selected as the most representative values from a large sampling of boiler emission data and have been related to boiler unit size and type, method of firing and fuel type. The accuracy of these emission factors will depend primarily on boiler equipment age, condition, and operation. New units operating at lower levels of excess air will have lower emissions than estimated. Older units may have appreciably more. Therefore, good judgement should accompany the use of these factors. These factors are from, Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors". It should be noted that currently MSW and RDF emission factors have not been established.

*a. Particulate emissions.* The particulate loadings in stack gases depend primarily on combustion efficiency and on the amount of ash contained in the fuel which is not normally collected or deposited within the boiler. A boiler firing coal with a high percentage of ash will have particulate emissions dependent more on the fuel ash content and the furnace ash collection or retention time than on combustion efficiency. In contrast, a boiler burning a low ash content fuel will have particulate emissions dependent more on the combustion efficiency the unit can maintain. Therefore, particulate emission estimates for boilers burning low ash content fuels will depend more on unit condition and operation. Boiler operating conditions which affect particulate emissions are shown in table 3-2. Particulate emission factors are presented in tables 3-3, 3-4, 3-5 and 3-6.

*b. Gaseous emissions.*

(1) *Sulfur oxide emissions.* During combustion, sulfur is oxidized in much the same way carbon is oxidized to carbon dioxide ($CO_2$). Therefore, almost all of the sulfur contained in the fuel will be oxidized to sulfur dioxide ($SO_2$) or sulfur trioxide ($SO_3$) in efficiently operated boilers. Field test data show that in efficiently operated boilers, approximately 98 percent of the fuel-bound sulfur will be oxidized to $SO_2$, one percent to $SO_3$, and the remaining one percent sulfur will be contained in the fuel ash. Boilers with low flue gas stack temperatures may produce lower levels of $SO_2$ emissions due to the formation of sulfuric acid. Emission factors for $SO_x$ are contained in tables 3-3, 3-4, 3-5, and 3-6.

(2) *Nitrogen oxide emissions.* The level of nitrogen oxides ($NO_x$) present in stack gases depends upon many variables. Furnace heat release rate, temperature, and excess air are major variables

Table 3-2

FACTORS RELATING TO PARTICULATE EMISSIONS

| | Level of Particulate Emissions High | Low |
|---|---|---|
| **Fuel characteristics:** | | |
| High ash content | X | - |
| High moisture content | X | - |
| Sizing | | |
| High degree of atomization or pulverization | - | X |
| **Boiler characteristics:** | | |
| High combustion rate | X | - |
| Dry bottom ash collection | X | - |
| Wet bottom ash collection | - | X |
| Flue-gas recirculation | X | - |
| Method of firing | | |
| Tangential | - | X |
| Horizontal | X | - |
| Spreader stoker | X | - |
| **Boiler operation:** | | |
| Improper oil pressure | X | - |
| Improper oil viscosity | X | - |
| High combustion air temperature | - | X |
| Nonuniform air flow (between register or air compartments) | X | - |
| High excess air | X | - |
| Low furnace temperature | X | - |
| **Equipment condition:** | | |
| Worn burner (nozzles, sprayer, plates, etc.) | X | - |
| Unclean or slagging boiler tube surfaces | X | - |

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affecting $NO_x$ emission levels, but they are not the only ones. Therefore, while the emission factors presented in tables 3-3, 3-4, 3-5, and 3-6 may not totally reflect on site conditions, they are useful in determing if a $NO_x$ emission problem may be present. Factors which influence $NO_x$ formation are shown in table 3-7.

## 3-8. Opacity

Visual measurements of plume opacity (para 5-3*j*) can aid in the optimization of combustion conditions. Particulate matter (smoke), the primary cause of plume opacity, is dependent on composition of fuel and efficiency of the combustion process. Smoke varies in color but is generally observed as gray, black, white, brown, blue, and sometimes yellow, depending on the conditions under which certain types of fuels or materials are burned. The color and density of smoke is often an indication of the type or combustion problems which exist in a process.

*a.* Gray or black smoke is often due to the presence of unburned combustibles. It can be an indicator that fuel is being burned without sufficient air or that there is inadequate mixing of fuel and air.

*b.* White smoke may appear when a furnace is operating under conditions of too much excess air. It may also be generated when the fuel being burned contains

TABLE 3-3

EMISSION FACTORS FOR BITUMINOUS COAL COMBUSTION WITHOUT CONTROL EQUIPMENT

| Furnace Size, $10^6$ Btu/hr heat input | Particulates[a] lb/ton coal burned | Sulfur oxides[b] lb/ton coal burned | Carbon monoxide lb/ton coal burned | Hydrocarbons[c] lb/ton coal burned | Nitrogen oxides lb/ton coal burned | Aldehydes lb/ton coal burned |
|---|---|---|---|---|---|---|
| Greater than 100 (Utility and large industrial boilers) | | | | | | |
| Pulverized - General | 16A | 38S | 1 | 0.3 | 18 | 0.005 |
| - Wet bottom | 13A[d] | 38S | 1 | 0.3 | 30 | 0.005 |
| - Dry bottom | 17A | 38S | 1 | 0.3 | 18 | 0.005 |
| Cyclone | 2A | 38S | 1 | 0.3 | 55 | 0.005 |
| 10 to 100 (large commercial and general industrial boilers) Spreader stoker[e] | 13A[f] | 38S | 2 | 1 | 15 | 0.005 |
| Less than 10 (commercial and domestic furnaces) | | | | | | |
| Underfed stoker | 2A | 38S | 10 | 3 | 6 | 0.005 |

a. The letter A on all units other than hand-fired equipment indicates that the weight percentage of ash in the coal should be multiplied by the value given. Example: If the factor is 16 and the ash content is 10 percent, the particulate emissions before the control equipment would be 10 times 16, or 160 pounds of particulate per ton of coal.
b. S equals the sulfur content (see footnote a above)
c. Expressed as methane.
d. Without fly-ash reinjection.
e. For all other stokers use 5A for particulate emission factor.
f. Without fly-ash reinjection. With fly-ash reinjection use 20A. This value is not an emission factor but represents loading reaching the control equipment.

From: Environmental Protection Agency, "Compilation of Air Emission Factors".

TABLE 3-4

EMISSION FACTORS FOR FUEL OIL COMBUSTION

| | Type of Boiler[a] | | | |
|---|---|---|---|---|
| | Power Plant | Industrial and Commercial | | Domestic |
| | Residual | Residual Oil | Distillate Oil | Distillate Oil |
| Pollutant | $lb/10^3$ gal | $lb/10^3$ gal | $lb/10^3$ gal | $lb/10^3$ gal |
| Particulate[b] | c | c | 2 | 2.5 |
| Sulfur dioxide[d] | 157S | 157S | 142S | 142S |
| Sulfur trioxide[d] | 2S | 2S | 2S | 2S |
| Carbon monoxide[e] | 5 | 5 | | 5 |
| Hydrocarbons (total, as $CH_4$)[f] | 1 | 1 | 1 | 1 |
| Nitrogen oxides (total, as $NO_2$) | 105(50)[gh] | 60[fi] | 22 | 18 |

a. Boilers can be classified, roughly, according to their gross (higher) heat input rate as shown below.
Power plant (utility) boilers: greater than $250 \times 10^6$ Btu/hr
Industrial boilers: greater than $15 \times 10^6$, but less than $250 \times 10^6$ Btu/hr
Commercial boilers: greater than $0.5 \times 10^6$, but less than $15 \times 10^6$ Btu/hr
Domestic (residential) boilers: less than $0.5 \times 10^6$ Btu/hr

b. Particulate is defined in this table as that material collected by EPA Method 5 (front half catch).

c. Particulate emission factors for residual oil combustion are best described, on the average, as a function of fuel oil grade and sulfur content, as shown below.
Grade 6 oil: $lb/10^3$ gal = 10 (S) + 3
Where: S is the percentage, by weight, of sulfur in the oil
Grade 5 oil: 10 $lb/10^3$ gal
Grade 4 oil: 7 $lb/10^3$ gal

d. S is the percentage, by weight, of sulfur in the oil.

e. Carbon monoxide emissions may increase by a factor of 10 to 100 if a unit is improperly operated or not well maintained.

f. Hydrocarbon emissions are generally negligible unless unit is improperly or not well maintained. In which case emissions may increase by several orders of magnitude.

g. Use 50 $lb/10^3$ gal for tangentially fired boilers and 105 $lb/10^3$ gal for all others, at full load, and normal (greater than 15 percent) excess air. At reduced loads, $NO_x$ emissions are reduced by 0.5 to 1 percent , on the average, for every percentage reduction in boiler load.

h. Several combustion modifications can be employed for $NO_x$ reductions: (1) limited excess air firing can reduce $NO_x$ emissions by 5 to 30 percent, (2) staged combustion can reduce $NO_x$ emissions by 20 to 45 percent, and (3) flue gas recirculation can reduce $NO_x$ emissions by 10 to 45 percent. Combinations of the modifications have been employed to reduce $NO_x$ emissions by as much as 60 percent in certain boilers.

i. Nitrogen oxides emissions from residual oil combustion in industrial and commercial boilers are strongly dependent on the fuel nitrogen content and can be estimated more accurately by the following empirical relationship:
lb $NO_2/10^3$ gal = 22 + 400 $(N)^2$
Where: N is the percentage, by weight, of nitrogen in the oil.
Note: For residual oils having high (greater than 0.5 percent by weight) nitrogen contents, one should use 120 lb $NO_2/10^3$ gal as an emission factor.

From: Environmental Protection Agency, "Compilation of Air Emission Factors".
U.S. Corps of Engineers

excessive amounts of moisture or when steam atomization or a water quenching system is employed.

*c.* A blue or light blue plume may be produced by the burning of high sulfur fuels. However; the color is only observed when little or no other visible emission is present. A blue plume may also be associated with the burning of domestic trash consisting of mostly paper or wood products.

*d.* Brown to yellow smoke may be produced by processes generating excessive amounts of nitrogen dioxide. It may also result from the burning of semi-solid tarry substances such as asphalt or tar paper encountered in the incineration of building material waste.

## 3-9. Sample problems of emission estimating

*a. Data Conversion.* Pounds per million Btu (lb/MMBtu) to grains per standard cubic foot (gr/std $ft^3$) dry basis is accomplished by equation 3-1.

$$E = C \times F_d \times \frac{20.9}{20.9 - \%O_2} \times 7000 \qquad \text{(eq. 3-1)}$$

where: E = pound/MMBtu
C = concentration, gr/std $ft^3$ dry
$\%O_2$ = percent by volume of oxygen in the flue gas
$F_d$ = dry F factor, std $ft^3$/MMBtu

| Fuel Type | $F_d$ |
|---|---|
| Anthracite coal | 10100 |
| Bituminous coal | 9780 |
| Fuel oil | 9190 |
| Gaseous fuels | 8710 |
| Wood | 9240 |
| Wood bark | 9600 |

TABLE 3-5

EMISSION FACTORS FOR NATURAL GAS COMBUSTION

| | Type of Unit | | |
|---|---|---|---|
| | Power Plant | Industrial Process Boiler | Domestic and Commercial Heating |
| Pollutant | lb/MCF gas | lb/MCF gas | lb/MCF gas |
| Particulates | 5-15 | 5-15 | 5-15 |
| Sulfur oxides ($SO_2$)[a] | 0.6 | 0.6 | 0.6 |
| Carbon monoxide | 17 | 17 | 20 |
| Hydrocarbons (as $CH_4$) | 1 | 3 | 8 |
| Nitrogen oxides ($NO_2$) | 700[b] | (120-230)[c] | (80-120)[d] |

a. Based on an average sulfur content of natural gas of 2000 gr/million cubic feet (MMCF).
b. Use 300 lb/MCF for tangentially fired units.
c. This represents a typical range for many industrial boilers. For large industrial units (greater than 100 MMBtu/hr) use the $NO_x$ factors presented for power plants.
d. Use 80 for domestic heating units and 120 for commercial units.

From: Environmental Protection Agency, "Compilation of Air Emission Factors".

*b. Sample Problem Number 1.* An underfed stoker fired boiler burns bituminous coal of the analysis shown below. If this unit is rated at 10 MM Btu per hour (hr) of fuel input, what are the estimated emission rates?

| Bituminous Coal Analysis | (percent by weight) |
|---|---|
| Ash | 13.0 |
| Sulfur | 0.7 |
| Heating value | 12,360 Btu/pound |

(1) Using table 3-3 (footnote e), particulate emissions are given as 5A pound/ton of coal where A is the percent ash in the coal.

*(a)* 5x13% ash = 65 pounds of particulate/ton of coal.

*(b)* 65 pounds/ton x ton/2000 pounds = .0325 pound of particulate/pound of coal

*(c)* $(.0325 \text{ lb/lb}) \times \frac{\text{lb of coal}}{12{,}360 \text{ Btu}} \times \frac{10^6 \text{ Btu}}{\text{MMBtu}}$

$= 2.63$ lbs/MMBtu

(2) Using table 3-3, $SO_2$ emissions are given as 38S pound/ton of coal, where S is the percent sulfur in the coal.

*(a)* 38 x .7% sulfur = 26.6 pounds of $SO_2$/ton of coal

*(b)* 26.6 pounds/ton = ton/2000 pounds = .0133 pound of $SO_2$/pound of coal

TABLE 3-6

EMISSION FACTORS FOR BARK AND WOOD WASTE COMBUSTION IN BOILERS

| Pollutant | Emissions lb/ton |
|---|---|
| Particulates [a] | |
| Bark [b] | |
| With fly-ash reinjection [c] | 75 |
| Without fly-ash reinjection | 50 |
| Wood/bark mixture [b] | |
| With fly-ash reinjection [c] | 45 |
| Without fly-ash reinjection | 30 |
| Wood [d] | 5-15 |
| Sulfur oxides ($SO_2$) [e] | 1.5 |
| Carbon monoxide [f] | 2-60 |
| Hydrocarbons [f] | 2-70 |
| Nitrogen oxides ($NO_2$) | 10 |

a. These emission factors were determined for boilers burning gas or oil as an auxiliary fuel, and it was assumed all particulates resulted from the waste fuel alone. When coal is burned as an auxiliary fuel, the appropriate emission factor from Table 3-3 should be used in addition to the above factor.

b. These factors based on an as-fired moisture content of 50 percent.

c. This factor represents a typical dust loading reaching the control equipment for boilers employing fly-ash reinjection.

d. This waste includes clean, dry (5 to 50 percent moisture) sawdust, shavings, ends, etc. and no bark. For well designed and operated boilers, use lower value and higher values for others. This factor is expressed on an as-fired moisture content basis assuming no fly-ash reinjection.

e. This factor is calculated by material balance assuming a maximum sulfur content of 0.1 percent in the waste. When auxiliary fuels are burned, the appropriate factors from Tables 3-3, 3-4, and 3-5 should be used in addition to determine sulfur oxide emissions.

f. Use lower values for well designed and operated boilers.

From: Environmental Protection Agency, "Compilation of Air Emission Factors"

TABLE 3-7

FACTORS AFFECTING $NO_x$ EMISSIONS

| Variable | Effect on $NO_x$ Emission | |
|---|---|---|
| **Increasing** | **Increase** | **Decrease** |
| Heat release rate | X | - |
| Heat quenching rate (water cooled furnaces) | - | X |
| Boiler capacity | X | - |
| Boiler load | X | - |
| Excess air | X | - |
| Furnace temperature | X | - |
| Combustion air temperature | X | - |
| Fuel nitrogen content | X | - |
| Fuel oxygen content | X | - |
| Fuel moisture content | - | X |
| Distance between burners | - | X |
| Number of burners per unit | - | X |
| Fuel/air mixing (turbulence) | X | - |
| Time available for particle burnout (tangentially fired boilers) | - | X |

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$$(c)\ (.0133\ \text{lb/lb}) \times \frac{\text{lb of coal}}{12{,}360\ \text{Btu}} \times \frac{10^6\ \text{Btu}}{\text{MMBtu}}$$

$$= 1.08\ \text{lbs/MMBtu}$$

(3) Using table 3-3, NOx emissions are given as 15 pounds/ton of coal.

*(a)* 15 pounds/ton x ton/2000 pounds = .0075 pound of NOx/pound of coal

$$(b)\ (.0075\ \text{lb/lb}) \times \frac{\text{lb of coal}}{12{,}360\ \text{Btu}} \times \frac{10^6\ \text{Btu}}{\text{MMBtu}}$$

$$= .61\ \text{lbs/MMBtu}$$

(4) If particulate emission must be reduced to .2 pounds/MMBtu, the required removal efficiency is determined as,

$$1 - \frac{.2}{2.63} = .924\ (92.4\%)$$

(5) If the oxygen in the flue gas is estimated at 5 percent by volume, what is the dust concentration leaving the boiler in grains/standard cubic foot (dry)?

Using equation 3-1

$$C = \frac{7000 \times 2.63}{9780} \times \frac{20.9 - 5}{20.9}$$

$$= 1.43\ \text{gr/std ft}^3\ \text{dry}$$

*c. Sample Problem Number 2.* A boiler rated at 50 MMBtu/hr burns fuel oil of the analysis shown below. What are the estimated emission rates?

| #6 Fuel Oil Analysis | (percent by weight) |
|---|---|
| Sulfur | 2 |
| Nitrogen | .2 |
| Heating Value | 150,000 Btu per gallon (gal) |

(1) Using table 3-4, particulate emissions are given as [10(S) + 3] pound/I 000 gal, where S is the percent sulfur in the fuel oil.

(*a*) $(10 \times 2\%\ \text{sulfur}) + 3 = 23$ pounds of particulate/1000 gal

(*b*) $$23\ \text{lbs/1000 gal} \times \frac{\text{gal of oil}}{150{,}000\ \text{Btu}} \times \frac{10^6\ \text{Btu}}{\text{MMBtu}} = .15\ \text{lb/MMBtu}$$

(2) Using table 3-4, $SO_2$ emissions are given as 157S pound/1000 gal, where S is the percent sulfur in the fuel oil.

(*a*) $157 \times 2\%\ \text{sulfur} = 314$ pounds/1000 gal

(*b*) $$314\ \text{lbs/1000 gal} \times \frac{\text{gal of oil}}{150{,}000\ \text{Btu}} \times \frac{10^6\ \text{Btu}}{\text{MMBtu}} = 2.09\ \text{lb/MMBtu}$$

(3) Using table 3-4, $NO_x$ emissions are given as $[22 + 400\ (N)^2]$ pound/1000 gal, where N is the percent nitrogen in the fuel oil.

(*a*) $22 + 400 \times (.2)^2 = 38$ pounds of $NO_x$/1000 gal

(*b*) $$38\ \text{lbs/1000 gal} \times \frac{\text{gal of oil}}{150{,}000\ \text{Btu}} \times \frac{10^6\ \text{Btu}}{\text{MMBtu}} = .25\ \text{lb/MMBtu}$$

*d. Sample Problem Number 3.* A commercial boiler rated at 10 MMBtu/hr fires natural gas with a heating value of 1000 Btu/ft$^3$. What are the estimated particulate and $NO_x$ emission rates?

(1) Using table 3-5, particulate emissions are given as a maximum of 15 pound per million cubic feet (MC F) of natural gas.

(*a*) $$15\ \text{lb/MCF} \times \frac{\text{MCF}}{10^6\text{ft}^3} \times \frac{10 \times 10^6\text{Btu}}{\text{hr}} \times \frac{\text{ft}^3}{1000\ \text{Btu}} = .15\ \text{lb/hr}$$

(*b*) $$.15\ \text{lb/hr} \times \frac{\text{hr}}{10\ \text{MMBtu}} = .015\ \text{lb/MMBtu}$$

(2) Using table 3-5 (footnote d), $NO_x$ emissions are given as 120 pound/MCF of natural gas.

(*a*) $$120\ \text{lb/MCF} \times \frac{\text{MCF}}{10^6\text{ft}^3} \times \frac{10 \times 10^6\text{Btu}}{\text{hr}} \times \frac{\text{ft}^3}{1000\ \text{Btu}} = 1.2\ \text{lb/hr}$$

(*b*) $$1.2\ \text{lb/hr} \times \frac{\text{hr}}{10\ \text{MMBtu}} = .12\ \text{lb/MMBtu}$$

*e. Sample Problem Number 4.* A spreader stoker fired boiler without reinjection burns bark and coal in combination. The bark firing rate is 2000 pound/hr. The coal firing rate is 1000 pound/hr of bituminous coal with an ash content of 10 percent and a heating value of 12,500 Btu/pound. What is the estimated particulate emission rate from this boiler?

(1) Using table 3-6, the bark firing particulate emission rate is given as 50 pounds/ton of fuel.

50 pounds/ton x ton/2000 pounds x 2000 pound/hr = 50 pounds/hr of particulate from bark.

(2) Using table 3-3, the coal firing particulate emission rate for a heat input of 12.5 MMBtu/hr is 13A pounds/ton of fuel.

(13 x 10) pound/ton x 1000 pound/hr x ton/2000 pound = 65 pounds/hr of particulate from coal.

(3) The total particulate emission rate from the boiler is,

50 pounds/hr from bark + 65 pounds/hr from coal = 115 pounds/hr